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Prototype Development of Milling Machine Using CAD/CAM

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Abstract: ***The development of unmanned machining systems has been a recent focus of manufacturing research. The conventional milling machine removes metal with a revolving cutting tool called a milling cutter. For this, CNC machines are in use. CNC machine operates on part program. This program includes several G-codes and M-codes. This program is generated by skilled operators. This may cause error in geometry. Also increases labor cost. Thus new technology of milling operation is conceptualized to reduce these problems using CAD/CAM. In this, firstly part design is created in CAD software like CATIA, ProE etc. This part design is fed in CAM software. Accordingly, coordinates forms. Also program is generated. According to that program, cutting tool operates to produce required part.***

Keywords: Milling machine, CAD/CAM, CNC machine, interfacing

1. Introduction

Milling Machines

Milling machines were first invented and developed by Eli Whitney to mass produce interchangeable musket parts. The milling machine removes metal with a revolving cutting tool called a milling cutter. With various attachments, milling machines can be used for boring, slotting, circular milling dividing, and drilling. This machine can also be used for cutting keyways, racks and gears and for fluting taps and reamers. Milling machines are basically classified as being horizontal or vertical to indicate the axis of the milling machine spindle. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer-type milling machines. Most machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power operated table feeds.

CNC Milling Machine

Computer Numerical Control (CNC) Milling is the most common form of CNC. CNC mills can perform the functions of drilling and often turning. CNC Mills are classified according to the number of axes that they possess. Axes are labeled as x and y for horizontal movement, and z for vertical movement. CNC milling machines are traditionally programmed using a set of commands known as G-codes and M-codes. G-codes and M-codes represent specific CNC functions in alphanumeric format.

New Technology

A table top mini milling machine is produced. This milling machine is interfaced with the CNC machine. Use of traditional manufacturing system using CNC requires part program to be fed by skilled operators. But sometimes there may be error and inaccuracy in manual part program. So as to reduce this error, new technology is conceptualized. In this technology, firstly part is designed in CAD tool. This part is transferred to the CAM tool. From geometry coordinates are generated and using these coordinates program is generated. According to program, cutting tool and workpiece moves to produce required part.

2. Literature Review

C. Doukas et al have given multisensory data for milling operations on the estimation of toolwear**.** A cutting depth of 0.5mm has been used along with a feedrate of 1000mm/min. The experiment has been repeated at the spindle speed of 1350rpm and 2700rpm, to investigate the effect of cutting speed on the wear level. Every 15 min the process is paused and the inserts are removed and inspected under an optical microscope for the measurement of the tool wear level.

This paper shows the results of a preliminary experimental investigation on tool-wear in end milling. Spindle torque and vibration signals were recorded during the process. A correlation between measured signals and tool-wear was attempted. Power consumption, as depicted from the current draw signal, can be associated with the sustainability evaluation of the milling operation, due to their directly correlation to the toolwear level.

Table 1: Setup variables

Variable	S=1350	S=2700
Cutting Speed	210m/min	420m/min
Feed Rate	1000mm/min	
Depth of cut	0.5mm	
Feed per tooth	0.15	0.5

A 3axis CNC knee mill, operating a spindle of 5Hp is being used for machining and it is capable of reaching approximately 3800 RPM. In order for the workpiece to be securely positioned on the machine table, an adaptor plate has been designed and manufactured, while also allowing the positioning of the acceleration sensor as close to the machining area as possible. Straight cutting passes have been performed, alongside the Y-axis of the machine, to minimize effects of feed direction changes. A cutting depth of 0.5mm has been used along with a feed rate of 1000mm/min. The experiment has been repeated at the spindle speed of 1350rpm and 2700rpm, to investigate the effect of cutting speed on the wear level. Every 15, 5 min the process is paused and the inserts are removed and inspected under an optical microscope for the measurement of the tool wears level.

Adam Hansela et al, has given idea for improving CNC machine tool geometric precision using manufacturing process analysis techniques. With the ever increasing demands for higher and higher accuracy on modern CNC equipment, the manufacturing processes for machining and assembling the structural components are an increasingly important factor in establishing a geometrically correct machine tool. Specifically, flatness, perpendicularity, parallelism, and straightness of interfacing surfaces determine whether the machine tool's basic accuracy. Exhibiting less geometric error allows other errors such as thermal growth, ballscrew pitch error, and control error to be isolated and more easily corrected.

Jig and fixture design

Parts of the machine tool are assembled in separate units as much as possible for optimal efficiency. X and Z rails are installed directly onto the bed, but the Y-axis rails are installed to the column in an independent station. For assembly workers to efficiently place and measure the rails during installation and adjustment, the column must be placed in the horizontal orientation on a jig with the rails facing upward. For stability and safety, a four point fixture was originally designed. The geometric errors are predominately a factor of the machine tool machining and assembly process. Multiple orientations during fixturing in both assembly and machining result in significant distortions to the final assembled product. These are a result of cutting forces, fixturing deformations, gravity deformations, and bolt force deformation. By analyzing each process in detail using virtual simulation techniques, a high fidelity model of the corresponding error at each manufacturing step can be achieved that is not physically measurable due to constraints of measurement equipment. Using simulated data as offset data in the machining process as well as in the jig and fixture design ensures a geometrically accurate final product.

Masakazu Soshia et al, has given the concept of Spindle rotational speed effect on milling process at low cutting speed**.** The spindle rotational speed fluctuates during milling due to intermittent cutting forces applied to the spindle, but the speed effect when machining with a relatively large cutter at low cutting speeds is still not clear. Table shows the basic specifications for the motor. The maximum rotational speed and torque of the servomotor is 5,500 min-1, and 700 Nm respectively.

Table 2: PMSM specification

Rotor size (O.D. × length), mm	160	300
Stator size (OD × Length), mm	240	410
Cutting Speed	210m/min	420m/min
Feed Rate	1000mm/min	
Depth of cut	0.5mm	
Feed per tooth	0.15	0.5

The focus of this paper is to investigate the effect of spindle servomotor dynamic characteristics on milling processes at various rotational speeds. Based on the simulation and experimental studies, it was found that the cutting speed fluctuation is not negligible at low operation speeds and that the spindle servomotor dynamics affect the machining process and tool life. Thus, it was concluded that the spindle dynamics have to be carefully evaluated and chosen when testing machinability of metals, especially low rotational milling applications typically required for machining of difficult-to-cut materials. A physical cutting test was conducted on a highly rigid 3-axis milling machine equipped with the high performance PMSM. A milling tool with a single insert was used to cut C55 carbon steel, and the results were compared to the simulation in order to verify model. The commanded rotational speed was set to 260 min-1 with required cutting torque of approximately 270 Nm. By adjusting the gain of the servomotor controller the high performance PMSM bandwidth was reduced to 100 Hz. The simulated motor response against the same torque at the same commanded rotational speed of 260 min-1. The predicted reduction in spindle speed and overshoot were relatively accurate, although there are differences while the cutter was engaging the material. This is mainly due to the torque disturbance being molded as a continuous input compared to the more complex physical torque profile, however this detail was not critical for the study.

Xiaoyan Zuo et al, revealed integrated geometric error compensation of machining processes on CNC machine tool". This paper presents an integrated geometric error model of machining system and compensation method on machine tools. Regarding a machine tool, fixtures, workpiece and tool as an assembly, an integrated geometric error model has been established. The integrated error is modeled by the propagation and the accumulation of errors based on Jacobian-Torsor theory. It is different with previous model, in this model; all the geometric errors of machining system are converted into the machine tool instead of the workpiece machining surface. As is well known in the machine tool, there are 21 geometric error of a 3-axis milling machine tool, which can be measured by laser interferometer. Based on this integrated model and machine tool error, the combination of geometric errors of machining system reflect on the machine tool can be predicted. Finally, a new compensation method is proposed to realize the error compensation, NC program is corrected corresponding NC codes according to the predicted errors during virtual machining before it is fed to the actual machining.

B. Denkenaa et al, has suggested adaptive cutting force control on a milling machine with hybrid axis configuration. In the re-contouring process of aircraft engine components, the unknown geometry and inhomogeneous material properties of the workpiece are major challenges. For this reason a new repair process chain is supposed which consists of noncontact geometry identification, process simulation and NC-path planning, followed by a force controlled milling process. A new milling machine prototype is employed to ensure an effective force control loop. By use of a magnetic guided spindle slide, higher dynamics and precise tracking are enabled.

Since variation of the process forces result in variable control plant characteristics, an indirect adaptive controller has been designed. Consequently, models of actuator and process are presented and the estimation of the present parameters by a recursive least square algorithm is outlined. Once the parameters are known, the control polynomials are calculated on the basis of a pole placement control approach. First experimental results of a force controlled milling process are put forward.

Modeling

In earlier times wherein computers were not yet developed, there has been a representation of using conventional media in designing. Ancient architects used text to abstractly describe the design process.2D drawings were later introduced and only expressed abstract visual thinking. The attempts have been continued to identify the nature of different design tools. On recent years, digital technology has been developed and matured at an unprecedented rate. This growth has led to a converging phenomenon that erodes the traditional boundaries of computing. Compared with conventional design media it is worth employing computer technology meaningfully to bring significant changes in the process of systems design and maintenance. The conventional approach involves the use of drawings and models as means of representing the basic convention. The type of models used in the design process can either be a physical or digital model. Both types were used as a means of solving complex problems that 2D drawings were unable to handle. 3D CAD models are three-dimensional computational representations of objects drawn in the x, y and z axes and illustrated in isometric, perspective or axonometric views. These views are achieved simply by rotating the viewpoint of the object. A 3D CAD model of an object in general provides the following advantages: (a) an object can be drawn once and then can be viewed and plotted from any angle; (b) A 3D CAD object holds mathematical information that can be used in engineering analysis, such as finite-element analysis and computer numerical control technology; and (c) A 3D CAD object can be shaded, rendered and assigned various materials for visualization. 3D CAD models can be generated by the use of various types of CAD software systems such as AutoCAD, Micro station and many more.

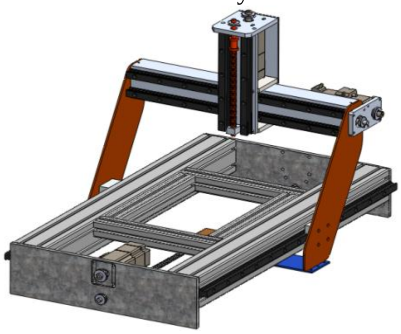

Figure 1: CAD model of milling machine

FEM

The finite element method (FEM) is one of the most used methods in engineering. These methods and programs based on it are fundamental usage in CAD. FEA / FEM are indispensable in all engineering analysis where high performance is required. The main purpose of the study is to see a practical application using FEA to improve design of a typical mechanical component.

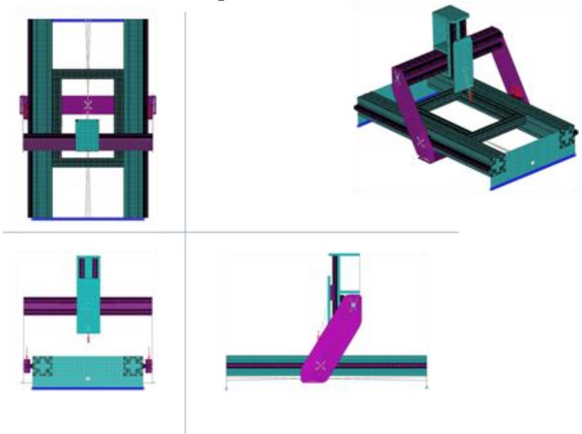

Figure 2: Hyper-mesh model of proposed milling machine

Materials used for milling machine are steel and aluminum. In this fig. portion of machine shown by blue is Steel material. Likewise portion of machine shown by purple is Aluminum. In this hyper mesh model, there are 463973 total elements and total nodes are 554403. In this, these elements are in 2D as well as 3D. 2D elements are in Triangular, Quadrilateral shape. Similarly, 3d shapes are in Pentahedral, Hexahedral shapes. Bluish colored portion denotes that part is fixed and constraint. Red colored arrow near gantry denotes loads applied to worktable and red colored arrow near spindle denotes moment.

Boundary Condition

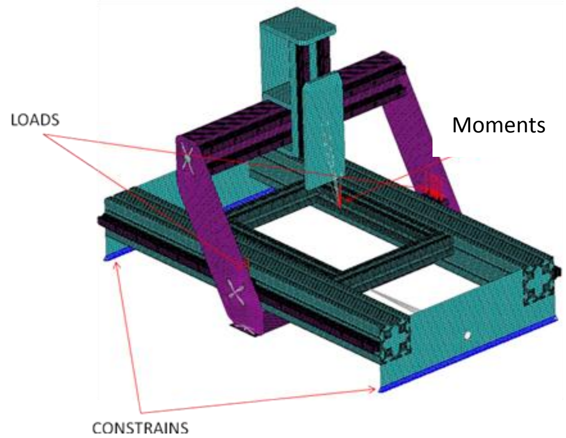

Figure 3: Boundary condition applied to milling machine

Defining Boundary Conditions:

1) To define a problem that results in a unique solution, it must specify information on the dependent (flow) variables at the domain boundaries Specify fluxes of mass, momentum, energy, etc. into the domain.
2) Defining boundary conditions involves:
   a. Identifying the location of the boundaries (e.g., inlets, walls, symmetry)
   b. Supplying information at the boundaries
   c. The data required at a boundary depends upon the boundary condition type and the physical models employed.

FEA Results - Linear Static Analysis (Nastran):

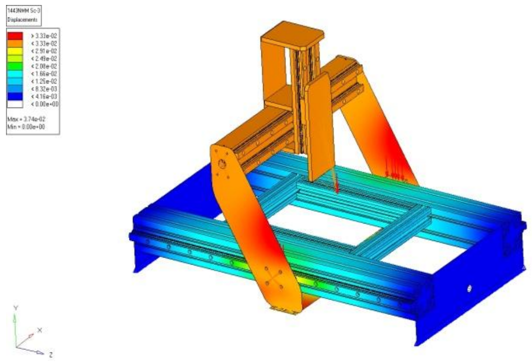

Figure 4: Finite elements results

Linear static Analysis

The linear static analysis of a milling machine is computed to calculate the loads and sustainability of a milling machine linear static analysis represents the most basic type of analysis. The term "linear" means that the computed response—displacement or stress, for example—is linearly related to the applied force. The term "static" means that the forces do not vary with time—or, that the time variation is insignificant and can therefore be safely ignored. An example of a static force is a building's dead load, which is comprised of the building's weight plus the weight of offices, equipment, and furniture. This dead load is often expressed in terms of lb/ft2 or N/m2. Such loads are often defined using a maximum expected load with some factor of safety applied for conservatism. In addition to the time invariant dead load described above, another example of a static load is an enforced displacement. For example, in a building part of the foundation may settle somewhat, inducing static loads. Another example of a static load is a steady-state temperature field. The applied temperatures cause thermal expansion which, in turn, causes induced forces. The static analysis equation is:

$$[K]\{U\} = \{f\}$$

Where [K] is the system stiffness matrix (generated automatically by NASTRAN for Windows (MSC/N4W), based on the geometry and properties), f is the vector of applied forces (which you specify), and u is the vector of displacements that NASTRAN computes. Once the displacements are computed, NASTRAN uses these to compute element forces, stresses, reaction forces, and strains.

Stress Analysis:

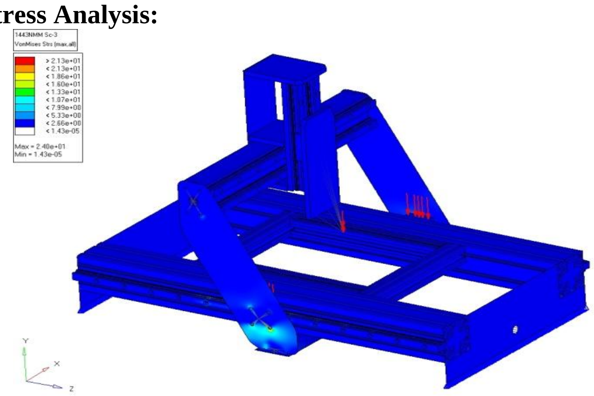

Figure 5: Stress Analysis of Milling Machine

The results of the stress analysis of a complete milling machine reveal that the maximum stress occurs in the frame where the overall mechanism for the movement is mounted. The maximum stress value is 14 MPa and the allowable stress of the M.S material is 24 MPa. Therefore, we can conclude that the design is safe enough for its application and working. If the stress will increase beyond the allowable stress of the material then there occurs a failure.

Part Programming Using CAD/CAM

A CAD/CAM system is a computer interactive graphics system equipped with software to accomplish certain tasks in design and manufacturing functions. One of the important tasks performed on a CAD/CAM system is NC part programming. In this method of part programming, portions of the procedure usually done by the part programmer are instead done by the computer. The two main tasks of a part programmer in a computer assisted programming are

a) Defining the part geometry and
b) Specifying the tool path.

The proposed methodology is used to automate both of these tasks.

Tool path generation using CAD/CAM:

The second task of the NC programmer in computer-assisted part programming is tool path specification. The first step in specifying the tool path is to select the cutting tool for the operation. Most CAD/CAM systems have tool libraries that can be called by the programmer to identify what tools are available in the tool crib. The programmer must decide which of the available tools is most appropriate for the operation under consideration and specify it for the tool path. This permits the tool diameter and other dimensions to be entered automatically for tool offset calculations. If the desired cutting tool is not available in the library, an appropriate tool can be specified by the programmer. It then becomes part of the library for future use.

The next step is tool path definition. There are differences in capabilities of the various CAD/CAM systems, which result in different approaches for generating the tool path. The most basic approach involves the use of the interactive graphics system to enter the motion commands one-by-one, similar to computer-assisted part programming. Individual statements in APT or other part programming language are entered and the CAD/CAM system provides an immediate graphic display of the action resulting from the command, thereby validating the statement.

A more-advanced approach for generating tool path commands is to use one of the automatic software modules available on the CAD/CAM system. These modules have been developed to accomplish a number of common machining cycles for milling, drilling and turning. They are subroutines in the NC programming package that can be called and the required parameters given to execute the machining cycle.

Introduction to Powermill:

PowerMILL is a stand-alone machining package, which can quickly create gouge free cutter paths on imported component data. PowerMILL supports Wireframe, Triangle, Surface, and Solid models created by other Delcam products or from neutral formats such as IGES. If the relevant PS-Exchange translators are purchased PowerMILL will directly import data created by the majority of non-Delcam packages.

PowerMILL Environment:

1. Double click on the PowerMILL icon.
2. Pull Down menus are located across the top of the PowerMILL window. By placing the mouse over the menu and clicking with the left mouse key, this will open up the relevant submenu. Further selection can be done by moving the cursor along a right arrow ( )

The Main toolbar is as shown on the following page. Each icon has a specific function and by holding the cursor over it, an appropriate description (or ToolTips) is displayed.

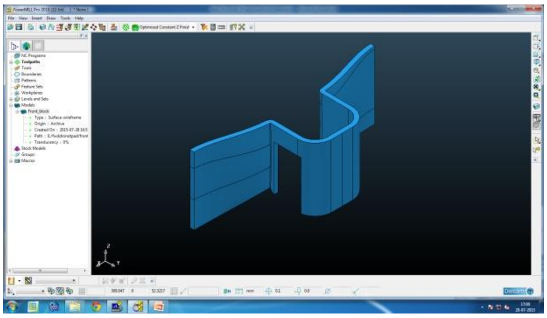

Figure 6: PowerMILL environment

On the right hand side of the screen is the Viewing toolbar. By selecting one of the icons a different view of the model and global transform is displayed in the central or graphics area.

PowerMILL

For the first exercise an existing model will be imported and used to illustrate some of the basic visual display options.

1) Select File -> Import Model.
   The open examples form appears and the large icon e.g. provides access to an area within the PowerMILL product software tree where sample models are stored.
   The icons marked 1 and 2 can be customized by the user to locate areas where data for live jobs are stored.
2) Click on the e.g. icon.
3) Select the phone.dgk (For example) model and then click on Open.
   The phone model is displayed as a wireframe viewed down the Z-axis. Only part of the model is visible, as it is too large to fit in the current view. To display the whole model the Resize to fit icon in the Viewing toolbar is selected.
4) In the Viewing toolbar, select the Resize to fit icon. The view of the model is scaled to the full screen
5) Select the ISO 1 icon.
   You can now see the entire model quite clearly in an isometric wireframe view.
   To see it shaded you need to select the shaded wire option.
6) Select the Shaded Model icon.
   This displays the shading on top of the wire. To remove the wire view and show the model as shaded only, click on the pressed in wire button.
7) Select the Wire Model icon.
   By pressing the wire icon again, the wireframe is hidden showing the model only in shaded.
8) Click on the Shaded Model icon and then click on the wire view icon.
   Try the other Viewing icons and observe the results.
   Sometimes it is useful to be able to see inside a model. In order to do this, the model can be made translucent.
9) Select the Shaded Model icon.
10) Right Click over the Model and select Translucency from the menu.
11) Enter the percentage translucency you require
    (0 percent = opaque, 100 percent = transparent)
    The model is displayed in translucent shaded mode allowing the user to see internal details
12) To return to normal shading set the translucency to Zero.

4. Conclusion

With increasing demand for small scale high precision parts in various industries, the market for small scale machine tools has grown substantially. Using small scale machine tools has grown substantially. Using small machine tools to fabricate small scale parts can provide both flexibility and efficiency in manufacturing approaches and reduce capital cost, which is beneficial for small business owners. In this thesis a small scale 3 axis milling machine is designed and analyzed. During the structure design stage the machine structure is explored and analyzed. Critical components such as linear guides, motors are selected among few different options. The best value components are selected to accommodate stiffness requirement and budget constraints.

In this project, firstly CAD model has been created using SolidWorks software. Then this CAD model is imported to CAM software such as PowerMILL. Then input commands are provided for cutting tool features such as tool diameter, depth of cut, length of cut etc. Then accordingly tool path is generated and part program is prepared.

In this way, human labor cost can be reduced; more accurate component can be manufactured automatically. It reduces total production lead time. It makes it possible to see how the component will be produced. Program can be generated in shortest time. It is more flexible. It requires less investment cost. It provides improved surface finish. It reduces manufacturing cost. It reduces tool loads. It provides high speed machining.

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